

**SOLAR WIND SPUTTERING OF LUNAR SOIL ANALOGS: THE EFFECT OF IONIC CHARGE AND MASS** H. Hijazi<sup>1</sup>, M. E. Bannister<sup>1</sup>, H. M. Meyer III<sup>2</sup>, C.M. Rouleau<sup>3</sup>, A. F. Barghouty<sup>4</sup>, D.L. Rickman<sup>4</sup>, and F. W. Meyer<sup>1</sup> (meyerfw@ornl.gov), <sup>1</sup>Physics Division, Oak Ridge National Laboratory, Oak Ridge, TN 37831-6372 USA, <sup>2</sup>Materials Science and Technology Division, Oak Ridge National Laboratory, Oak Ridge, TN 37831-6064 USA, <sup>3</sup>Center for Nanophase Materials Sciences, Oak Ridge National Laboratory, Oak Ridge, TN 37831-6488, <sup>4</sup>MSFC, Huntsville, AL 35805

**Introduction:** In this contribution we report sputtering measurements of anorthite, an analog material representative of the lunar highlands, by singly and multicharged ions representative of the solar wind. The ions investigated include protons, as well as singly and multicharged Ar ions (as proxies for the heavier solar wind constituents), in the charge state range +1 to +9, and had a fixed solar-wind-relevant impact velocity of ~310 km/s or 500 eV/amu. The goal of the measurements was to determine the sputtering contribution of the heavy, multicharged minority solar wind constituents in comparison to that due to the dominant H<sup>+</sup> fraction.

**Experimental Approach:** The measurements were performed at the ORNL Multicharged Ion Research Facility using a quartz microbalance approach for determination of total sputtering yields, together with quadrupole mass spectrometry [1] for relative mass resolved sputtering yields. The anorthite target was deposited as a thin film onto a gold-coated quartz sensor using Pulsed Laser Deposition (PLD). X-ray Photoelectron Spectrometry (XPS) analysis confirmed the thin film stoichiometry to be close to that expected for bulk anorthite.

2-D spatial profiles of the ion beams incident on the microbalance were measured using a stepper-motor controlled wire scanner under PC control located immediately upstream of the microbalance, and permitted accurate determination of the microbalance response, which depends sensitively on beam size. A beam flag insertable in front of the microbalance was used for ion beam current determination during the sputtering measurement.

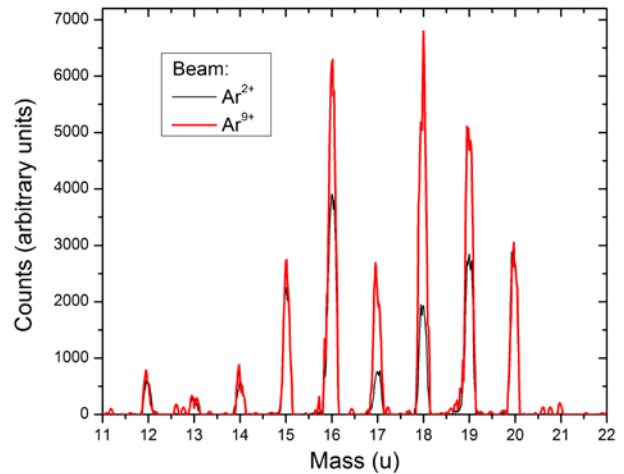
**Results:** Table I summarizes the total sputtering yield results, and provides comparison to simulated sputtering yields using the SRIM code [4] in the case of the singly charged ions.

**Table I:** Measured and simulated anorthite sputter yields at 311 km/s impact velocity, in units of anorthite mass (278 amu). The SRIM value for Ar<sup>+9</sup>, denoted by the \*, includes the effect of potential oxygen sputtering.

ion	Experiment	SRIM result
H <sup>+</sup>	0.0038±0.0007	0.0042
Ar <sup>+</sup>	0.27±0.03	0.251
Ar <sup>+9</sup>	0.39±0.13	0.407*

The experimental total sputtering yields shown in the table were corrected for ion implantation using reflection coefficients determined using SRIM.

In Figure 1 we compare the relative sputtering yields of OH<sub>n</sub> species for Ar<sup>+2</sup> and Ar<sup>+9</sup>. The two spectra were normalized to the same incident beam particle current. All the OH<sub>n</sub> peaks are seen to be significantly enhanced for the case of incident Ar<sup>+9</sup>. Taking the total O sputtering to be the sum of all the OH<sub>n</sub> peaks, the enhancement of O sputtering by Ar<sup>+9</sup> relative to that by Ar<sup>+2</sup> is calculated to be a factor of 2.2. Enhancing the SRIM O sputtering yield by this factor, gives a total



**Figure 1:** Comparison of OH<sub>n</sub> emission by 500 eV/amu impact of Ar<sup>+2</sup> and Ar<sup>+9</sup> ions on anorthite. The peaks at mass 20 are due to the incident Ar beams, and show the consistency of the applied normalization. Peaks at masses above the shown range show no charge state enhancement.

sputtering yield of 0.407, which is to be compared with the experimental value of 0.39.

**Discussion:** The above total and mass resolved sputtering results suggest that potential sputtering enhances only the amount of oxygen sputtered from the anorthite sample, and is consistent with the mechanism of defect mediated sputtering which has been observed in other metal oxides [5]. The presence of significant kinetic sputtering in addition to the potential O sputtering minimizes surface metallization which has been shown to inhibit potential sputtering above critical ion fluences at very low ion impact energies. At the present

solar wind relevant energy, in an extended sputtering run, we have reached fluences in excess of  $3 \times 10^{16}/\text{cm}^2$  without observing such inhibition, a dose more than 3 orders of magnitude larger than that at which such an inhibition was observed [6] for  $\text{Xe}^{+14}$  impact on  $\text{Al}_2\text{O}_3$  at 38 km/s (76 eV/amu) impact velocity.

From the tabulated mean neutralization potential energies [2] of other heavy multicharged solar wind constituents in comparison to that of  $\text{Ar}^{+9}$ , which is less than 1000 eV, significantly larger potential sputtering enhancements than the presently observed factor 2.2 should be anticipated for yet higher charge states. Together with the significantly higher kinetic sputtering yields of the heavier solar wind constituents (a factor exceeding 70 for the case of  $\text{Ar}^{+9}$  in comparison with iso-velocity protons, see Table 1) such potential sputtering enhancements can easily increase the sputtering efficacy for the heavy multicharged solar wind constituents relative to protons by more than 2 orders of magnitude. For this reason, despite their relatively low abundance, it is important to include the effects the minority solar wind species in solar wind-lunar surface interactions.

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